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ANOMALIES OF HEAT TREATMENT TO CARBURIZED STEELS

May, 1974

by JOHN VETTRAINO, LT DANIEL BURROWS

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ANOMALIES OF HEAT TREATMENT TO CARBURIZED STEELS

BY
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MATERIALS FUNCTION

ABSTRACT

Three steels which are commonly used in tank-automotive gears were carburized to produce three different case microstructures. Tests simulating actual wear and fatigue on gear teeth under high contact loads were made using carburized rollers. A comparison of all test data was compiled and evaluated.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

INTRODUCTION

Despite the fact that carburized gears have been used for power transmission for many years, engineers and metallurgists still lack a complete understanding of the numerous metallurgical factors which affect gear life. This seems to be especially true when an interpretation is sought as to whether certain non-martensite microstructures present in the carburized case are beneficial or detrimental to surface durability.

Many metallurgists, heat treaters and engineers frown on a process that will produce any amount of retained austenite, bainite, network cementite, grain boundary oxidation or decarburization in the outer surface layers of the case. Others seem to feel that some austenite is not detrimental, but actually beneficial to gear life. For example, some gear specifications require refrigeration treatments to insure transformation of all retained austenite while others allow as much as 25%. In examining new, as well as failed gears, it is evident that gears produced today often contain one or more of the so-called detrimental metallurgical factors. How unsatisfactory these factors are and what effect they actually have on gear life are questions which have never been fully resolved. Knowledge of the effects of such variables could be used to establish more precise specifications which will further insure the attainment of reliable gears.

To study metallurgical structures' effect upon surface pitting of gears in this test program, a set of rollers was used to simulate gear action. When these rollers are placed under load, a compressive stress is generated at the point of contact. Frictional forces and thermal stresses create surface shear stresses which produce cracks and subsequent pitting.

Three distinct types of failure occur on steel hardened parts. Sub-surface pitting occurs under the condition of pure rolling, case crushing occurs with insufficient core strength, and surface pitting occurs when rolling and sliding are present. Only surface pitting tests were conducted in this study.

OBJECTIVE

Evaluate the surface durability of various carburized case microstructures under high contact stresses and sliding.

CONCLUSIONS

Case microstructures consisting of cementite networks and tempered martensite were superior to those containing bainite and martensite or retained austenite and martensite. Surface wear was greatest in case structures that were relatively soft and contained retained austenite.

TEST EQUIPMENT & PRODEDURE

The geared roller test machine used for testing carburized rollers is shown in Figure 1. This machine was used to produce pitting failures on the rollers.

A 1-inch diameter roller and a 5-inch diameter roller (Figure 2) were selected for these tests. The large roller is 0.5 inches wide and the smaller roller is 0.875 inches in width. The smaller roller has a cylindrical surface, and the larger roller a crowned radius of 10R. Figures 3 (a, b &c) show the position and design of the rollers. This arrangement minimizes the alignment problems and eliminates edge effects.

The test rollers are mounted on two parallel horizontal shafts, 3 inches apart, which are geared together. The three-inch center distance between the two shafts is maintained by the rollers. Power input is through the lower shaft, the upper shaft being driven from it by a set of phasing gears.

The surface velocity ratio of the rollers V_1/V_2 can be varied by changing the ratio of the phasing gears. A gear ratio of 3.5:1 was used throughout all of the tests. This ratio produced a slower surface velocity and negative sliding on the smaller roller.

The upper frame is hinged at one end to the base that holds the lower shaft to form a "nutcracker" type of mechanism. It can be pivoted upward for installation or inspection of the test specimens. There are two double-row, pressure lubricated caged roller bearings on each shaft, one on either side of the test rollers. The entire assembly is housed in a test box which serves as an oil reservoir. The oil is supplied by jets to the bearing and rollers at a controlled temperature. A 2000 watt-155 volt immersion heater controlled by a Fenwal Switch allows the oil temperature to be maintained. In all of the tests conducted, an APG PD No. 1 oil was used at an average temperature of 325^{o}F.

The upper shaft is mounted on the upper frame. The load is applied to the free end of this frame through a lever arrangement which is actuated by a pneumatic Rotochamber. The rollers are located mid-way between the pivot point and the point of load application. The lightest load that can be applied without a counterbalance is 66 pounds, which is the force extended by the upper frame in the operating position. A pressure of 60 psi on the 7.75-inch diameter Rotochamber piston will produce the maximum recommended normal load for operation of 8000 pounds on the rollers. The actual load was determined using a calibrated strain-gaged load rod. The pressure gage was used to maintain stability of the load. A load of 3750 pounds was applied during the test.

The actual Hertz compressive stress was calculated, using the calibration data developed in Figures 4 (a, b & c). Figure 4 (a) correlates gage pressure to the strain on the load rod. Figure 4 (b) relates load rod strain to load rod load (applied load). Figure 4 (b) was obtained by applying tensile loads to the strain-gaged load rod in a universal tensile machine. The total load on the rollers represents the load transmitted by the load rod (applied load) plus the load of the upper frame (66 pounds). The Herz compressive stress vs. total load is shown in Figure 4 (c).

Loads of 435,000 PSI (Hertz compressive stress) were applied at 1745 RPM so that roller failure occurred between 1 and 15 million cycles. The rollers were run continuously except for daily inspection until a surface pit formed. The occurrence of a pit was evident by a change in noise level or by excessive machine vibration. Figure 5 shows a typical failure on the smaller roller. Vibration sensitive switches were used to shut off the power when a pit occurred.

TEST MATERIAL & HEAT TREATMENT

In this study, three alloy grade steels, 8620, 4820 and 4620 were selected as representative of the steels used in tank-automotive gear applications. The composition of the low to high nickel steels used is shown in Table I.

Six one-inch diameter roller specimens and six five-inch diameter roller specimens were machined from each of the steels.

Group "A" specimens (4620) were treated to obtain retained austenite; Group "B" (8620) were treated to obtain Bainite; Group "C" (4820) were treated to obtain network carbides.

The specimens were gas carburized in a Hevi Duty Lindberg furnace with 10% natural gas so the zone of maximum shear stress would be within the case. The rollers were ground to 10μinches RMS after heat treatment. The carburization treatment and the case obtained, after grinding, are described below:

a. Group "A" - Carburized at 1680°F for 6 hours, furnace cooled to 1480°F, quenched in agitated oil (100°F) and tempered at 300°F for 2 hours.

(1) This treatment produced a case microstructure with tempered martensite, retained austenite and scattered areas of other transformation products.

(2) The retained austenite was present to 0.015-inch depth. Figure 6 shows a representative Group "A" surface microstructure.

(3) Group "A" specimens had a surface hardness of Rockwell C56-58, a total case of 0.050-0.055 inches, and an effective case (Rockwell C50) to a 0.040-0.045 inch depth.

b. Group "B" - Carburized at 1700°F for 6 hours, furnace cooled to 1480°F, quenched in agitated oil (100°F) and tempered at 300°F for 2 hours.

(1) The microstructure of the case consisted of tempered martensite with scattered areas of bainite.

(2) Figure 7 shows the representative microstructure of all "B" specimens. The specimens had a surface hardness which ranged from Rockwell "C" 58-61, a total case of 0.050-inch and an effective case of (Rockewll C50) to 0.045-inch depth.

c. Group "C" - Carburized at 1700°F for 7 hours, furnace cooled to 1480°f, quenched in agitated oil (100°F), and tempered at 300°F for 2 hours.

(1) This carburization treatment produced a grain boundary hyper-eutectic network with the matrix consisting of tempered martensite with very small amounts of high transformation products.

(2) Figure 8 shows a representative Group "C" surface microstructure. The surface hardness of these specimens ranged from Rockwell C60-63. The effective case (Rockwell C50) was 0.050-inch deep and the total case was 0.058-inch deep.

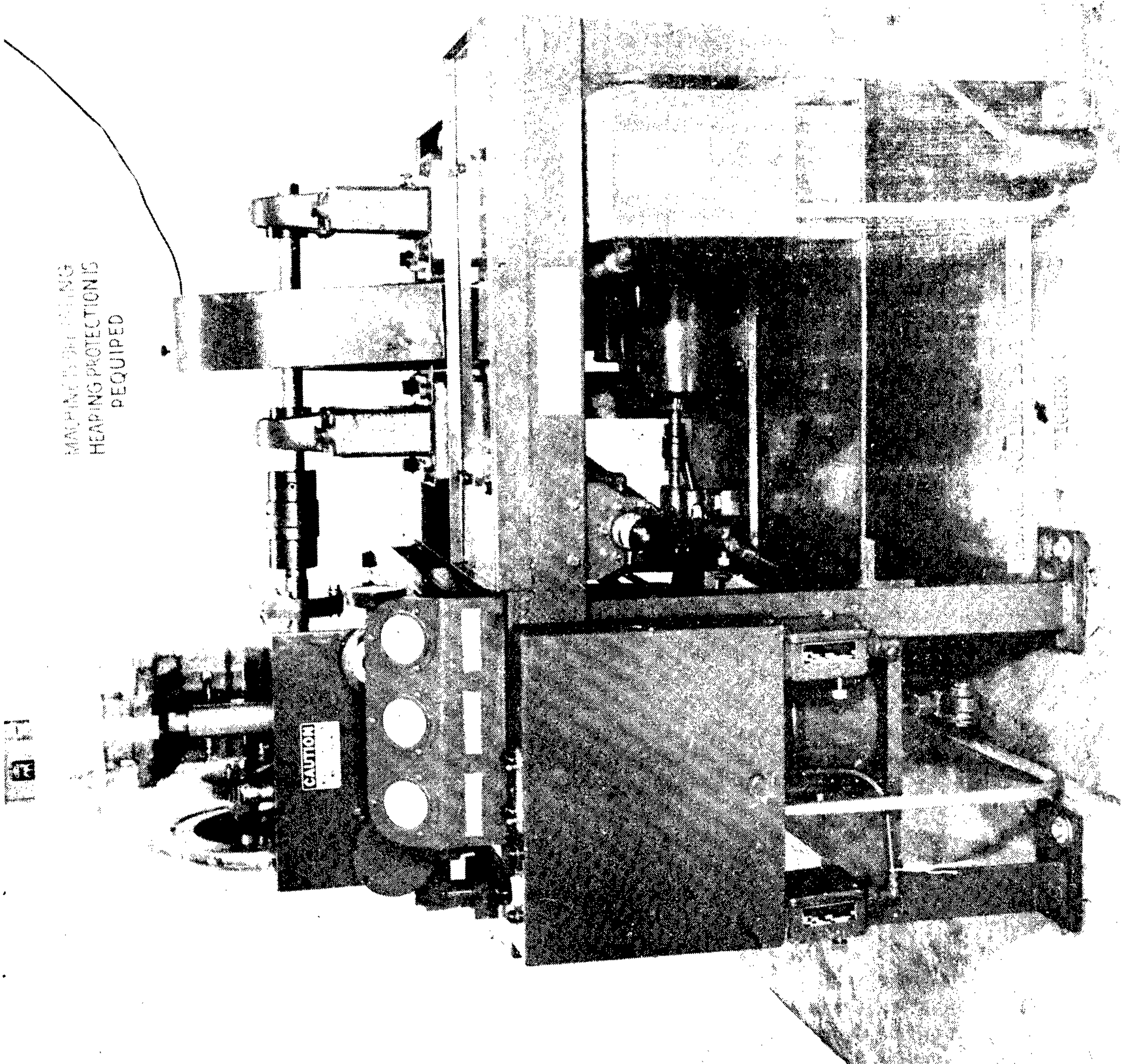
RESULTS AND DISCUSSION

The endurance limit for the three steel microstructures tested is shown in Table II. The data show that the surface durability of the roller specimens is more sensitive to the case microstructure than to the grade of alloy steel.

The shortest life of all the rollers tested were those in the "A" group. These rollers had a service life 18% less than the "B" group and 39% less than the "C" group. The combination of retained austenite and the lower-case surface hardness adversely affected fatigue. This poorer performance could have resulted from the instability of retained austenite; which, under high contact stresses, also hardens. If this highly-stressed structure caused micro cracks, they could act as nucli for formation of pits. Our examination of these rollers failed to determine the cause for their short life.

The "B" group of rollers that were treated to produce case microstructure containing bainite had fatigue lives that were 22% greater than the "A" group, but 26% less than the "C" group. These rollers contained a smaller percentage of bainite than originally planned. Thus, the mixed structure of martensite and bainite more closely represent the type of structure more often observed in commercially treated gears. Because excessive bainite in the surface layer was not achieved, these specimens are considered more representative of a normal rather than abnormal structure.

The "C" group of rollers which contained network carbides near the rolling surface had a surface life 65% longer than the "A" group and 34% longer than the "B" group rollers evaluated. It, thus, appears from these limited tests that the surface durability is enhanced by the presence of the network carbides rather than degraded. This might appear to conflict with our present tank-automotive philosophy for gears that considers grain boundary carbides as being detrimental. This criteria, however, is based, not solely upon high-gear contact stresses, but also upon the application of sudden loads. Further evaluation of these parameters, as well as the effect of large massive carbides, is also needed.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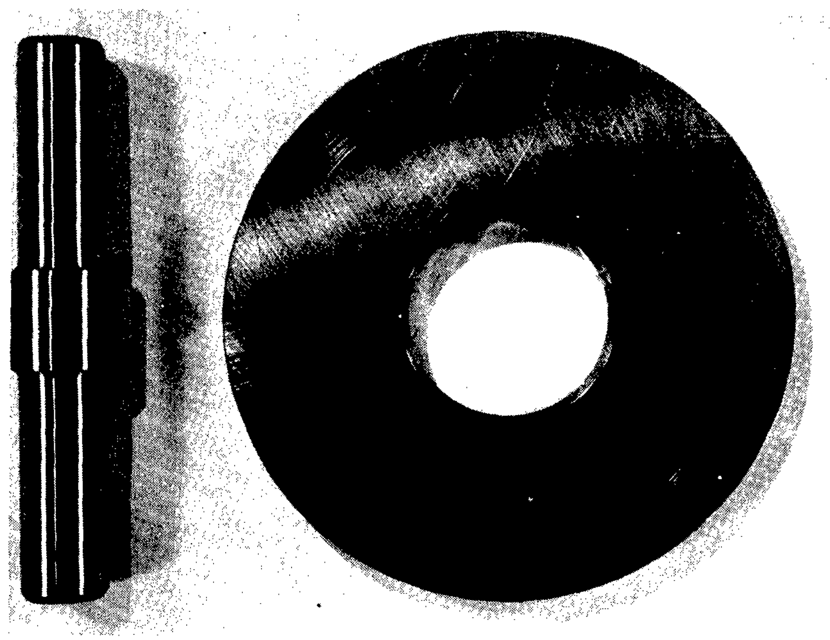
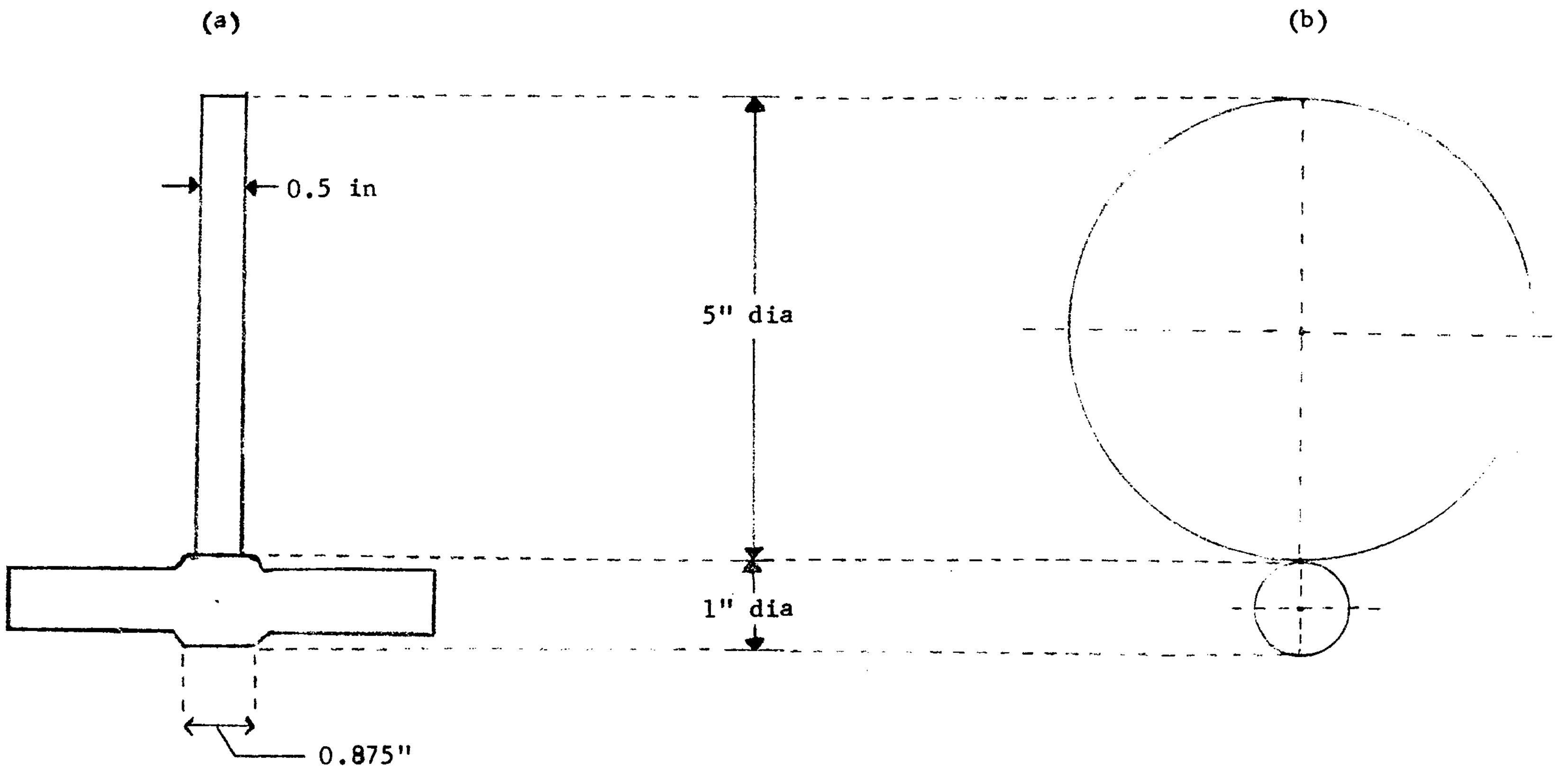


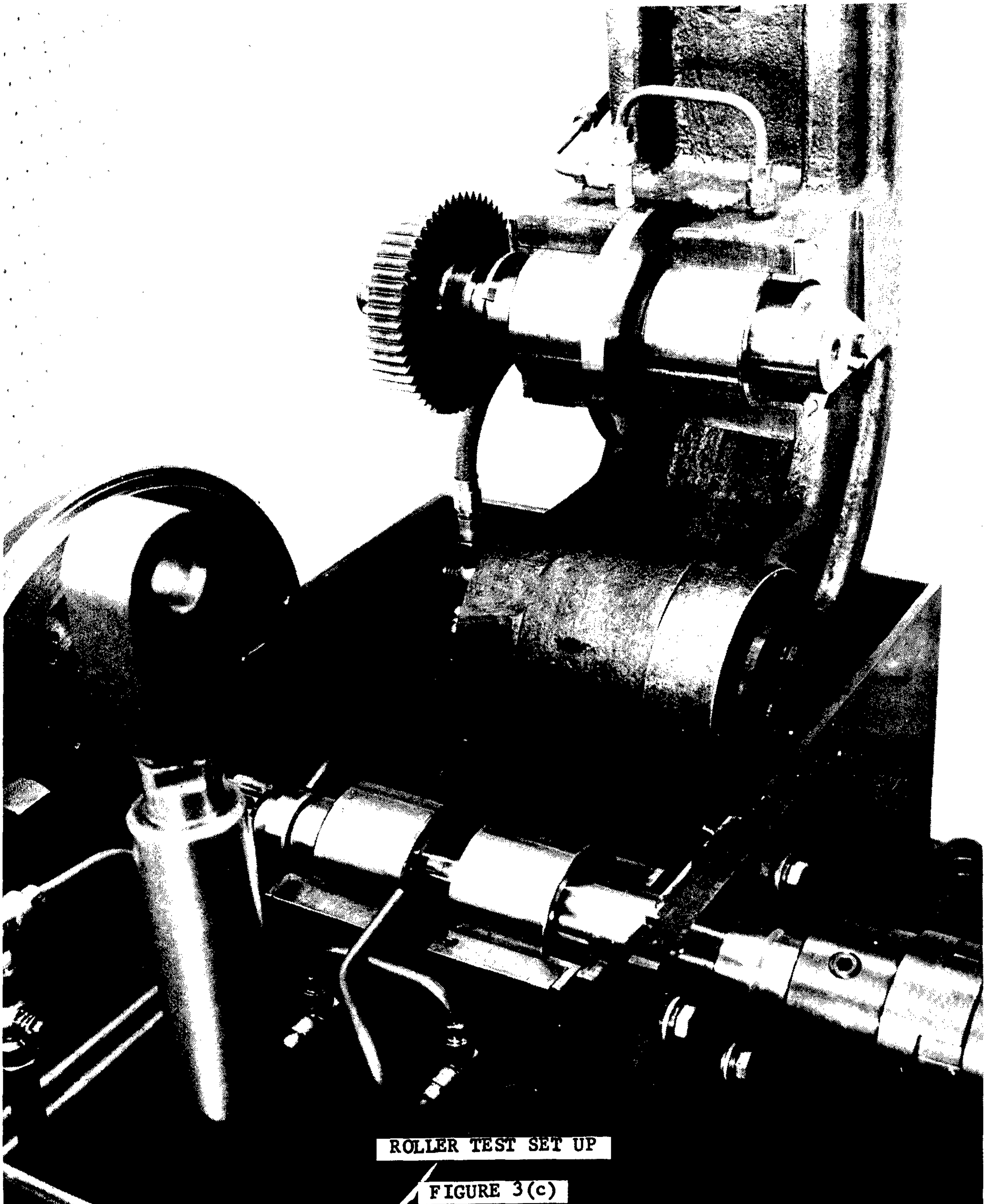
ROLLER TEST SPECIMENS
1.001" DIA SHAFT, 5.010" DIA ROLLER

FIGURE 2



ROLLER TEST SET UP

FIGURE 3



ROLLER TEST SET UP

FIGURE 3(c)

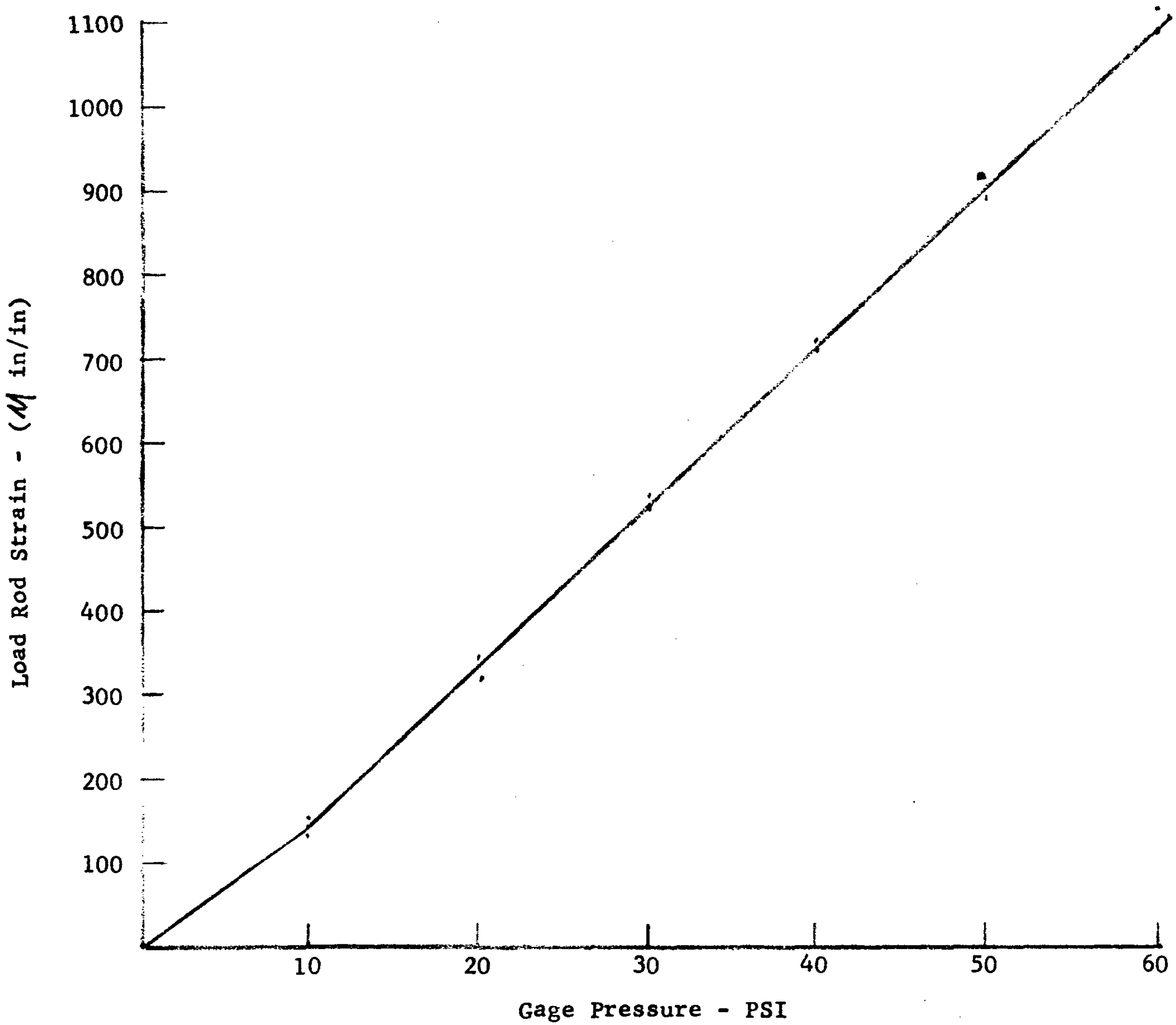


FIGURE 4(a) - GAGE PRESSURE VS LOAD ROD STRAIN

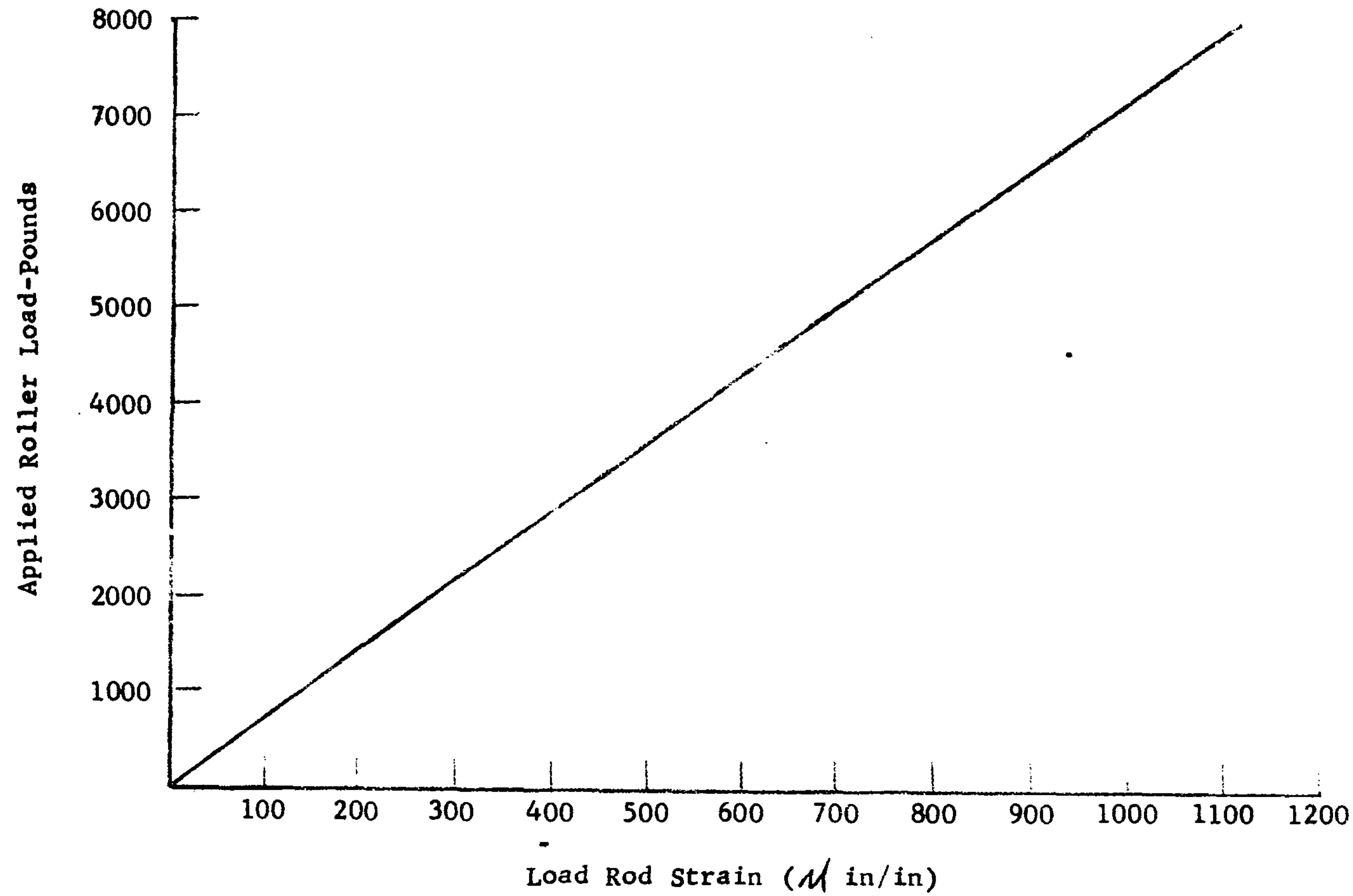


FIGURE 4(b) - LOAD ROD STRAIN VS APPLIED LOAD

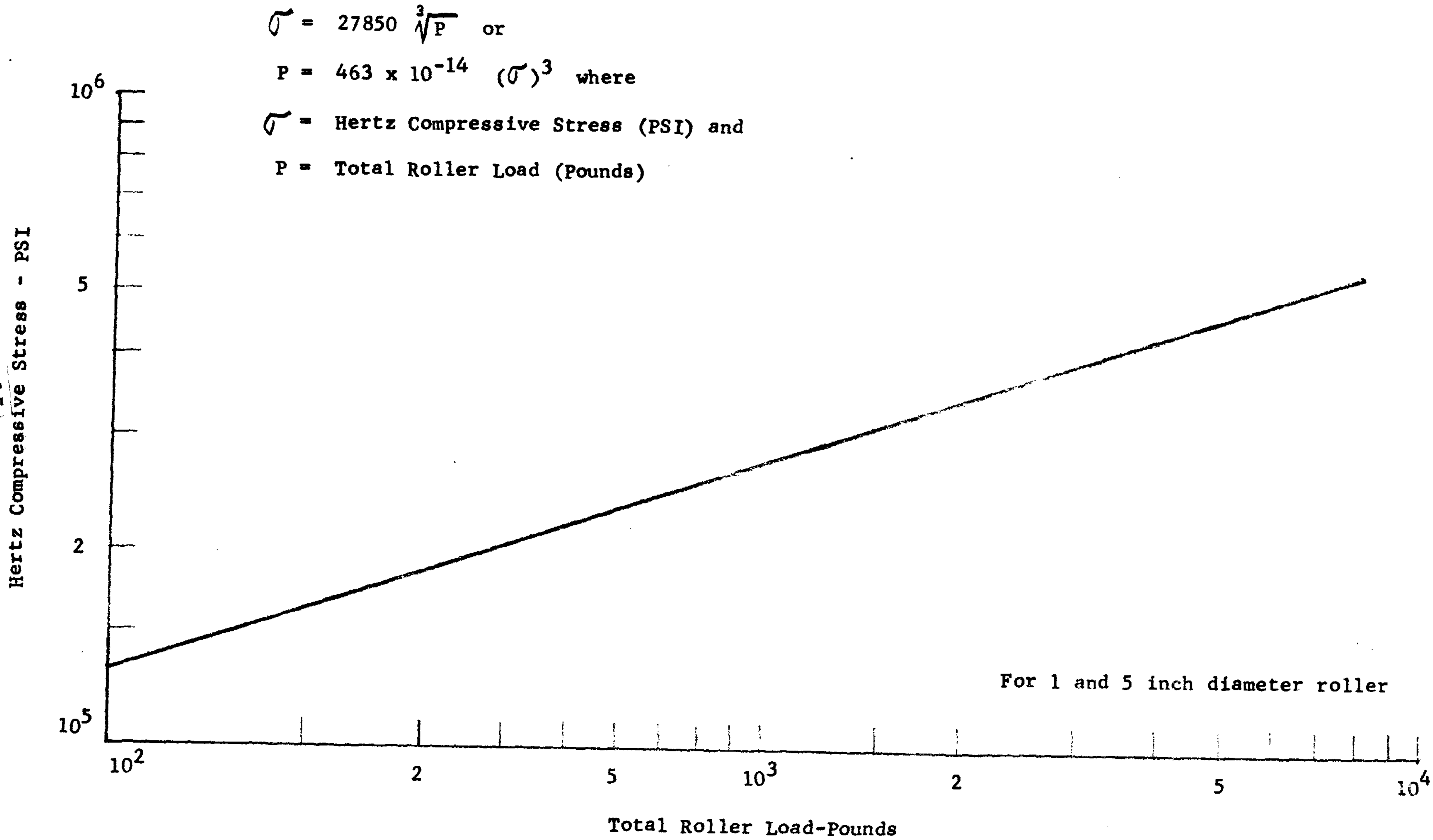
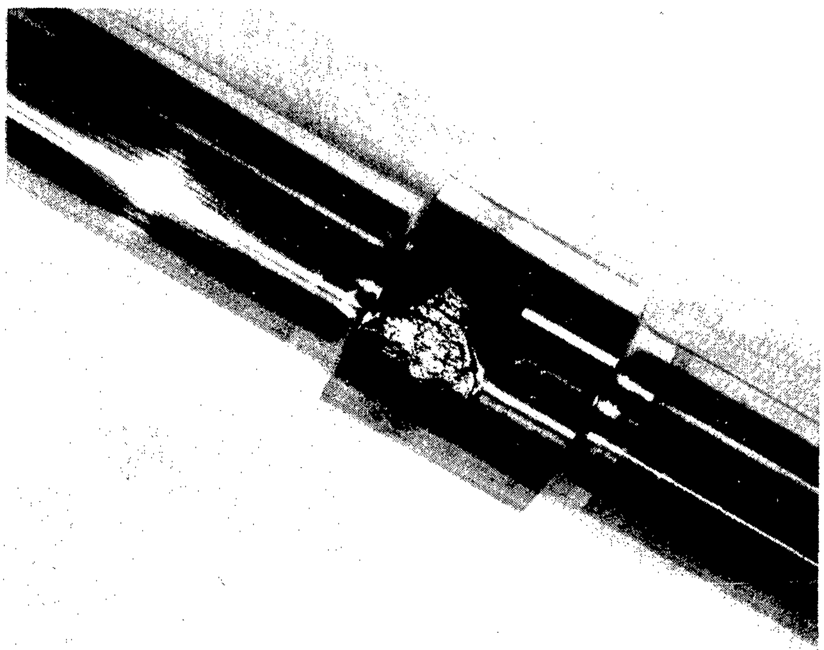
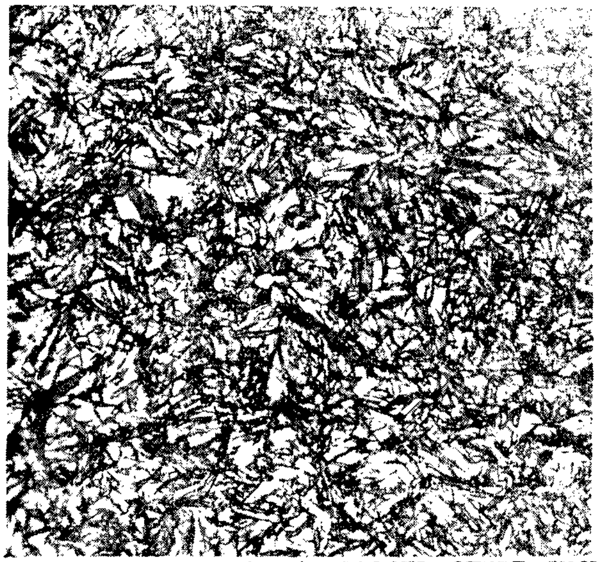


FIGURE 4(c) - TOTAL ROLLER LOAD VS HERTZ COMPRESSIVE STRESS



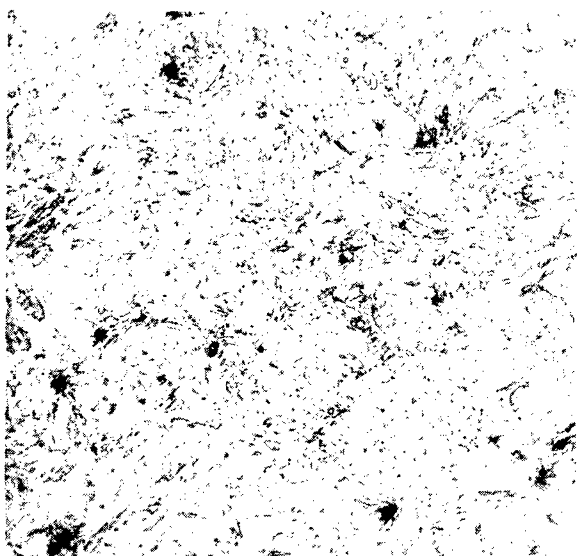
FAILURE OF SMALLER ROLLER

FIGURE 5



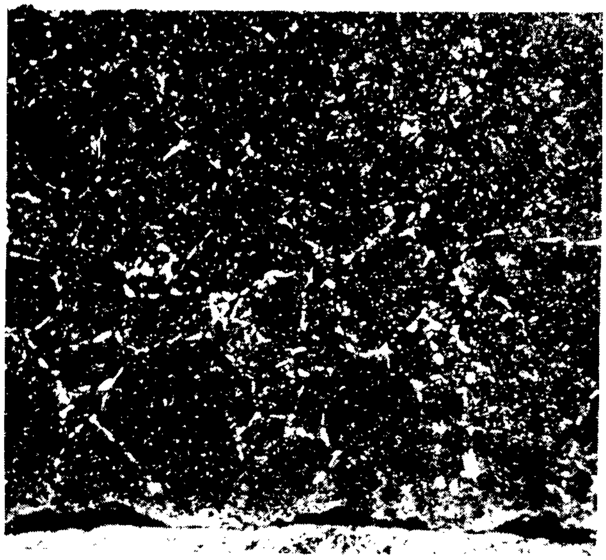
REPRESENTATIVE SURFACE MICROSTRUCTURE SHOWING RETAINED AUSTENITE, GROUP A, 500X, 2% NITAL

FIGURE 6



SURFACE MICROSTRUCTURE SHOWING TEMPERED MARTENSITE AND BAINITE, GROUP B, 500X, 2% NITAL

FIGURE 7



SURFACE MICROSTRUCTURE OF GRAIN BOUNDARY CARBIDE NETWORK, GROUP C, 500X, 2% NITAL

FIGURE 8

TABLE I

MATERIAL	C	Mn	P	S	Si	Ni	Cr	Mo
SAE 8620	0.22	0.88	0.030	0.035	0.24	0.68	0.58	0.24
SAE 4620	0.21	0.58	0.013	0.024	0.35	1.65	--	0.25
SAE 4820	0.20	0.55	0.002	0.002	0.33	3.35	--	0.28

CHEMICAL COMPOSITION OF STEELS

TABLE II

Group	Life Cycles		
A	2.51	2.72	2.51
	2.72	2.93	2.72
B	3.14	3.03	3.35
	3.35	3.35	3.46
C	4.19	4.29	4.50
	4.39	4.50	4.61

Endurance Limits X 10^{-6} Cycles at 1745 RPM and 400,000 PSI Hertz Compressive Stress.

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13. ABSTRACT

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GEARED ROLLER TESTS						
HERTZ COMPRESSIVE STRESSES						

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